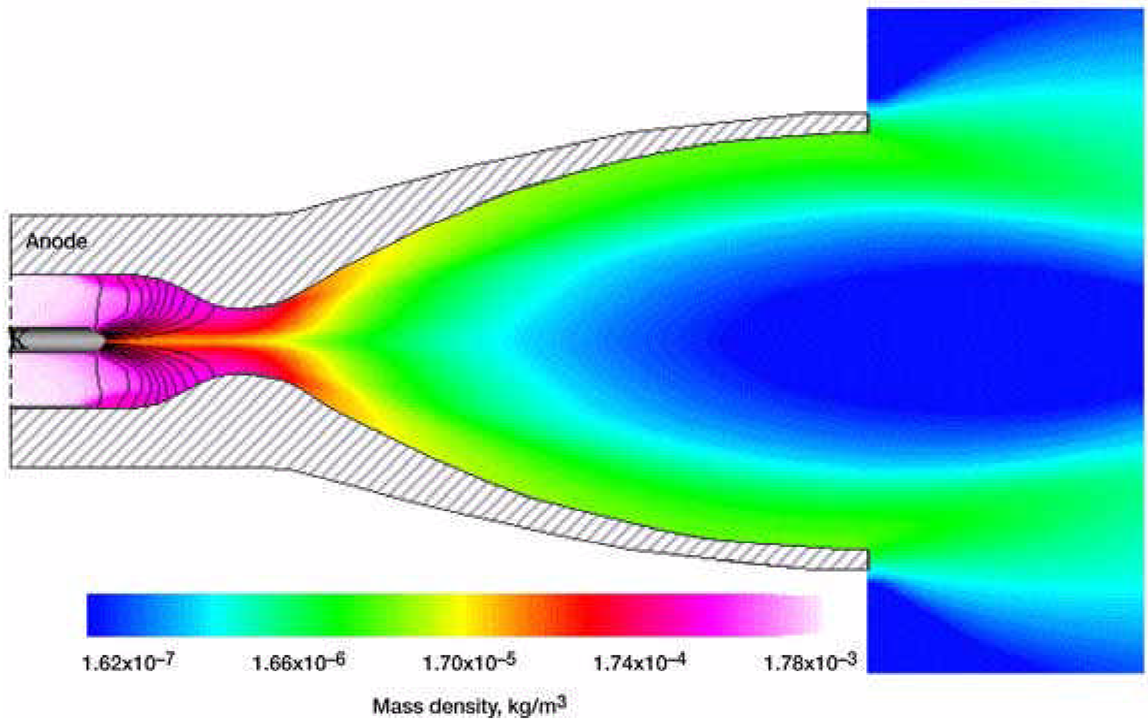
Magnetohydrodynamic MACH Code Used to Simulate Magnetoplasmadynamic Thrusters

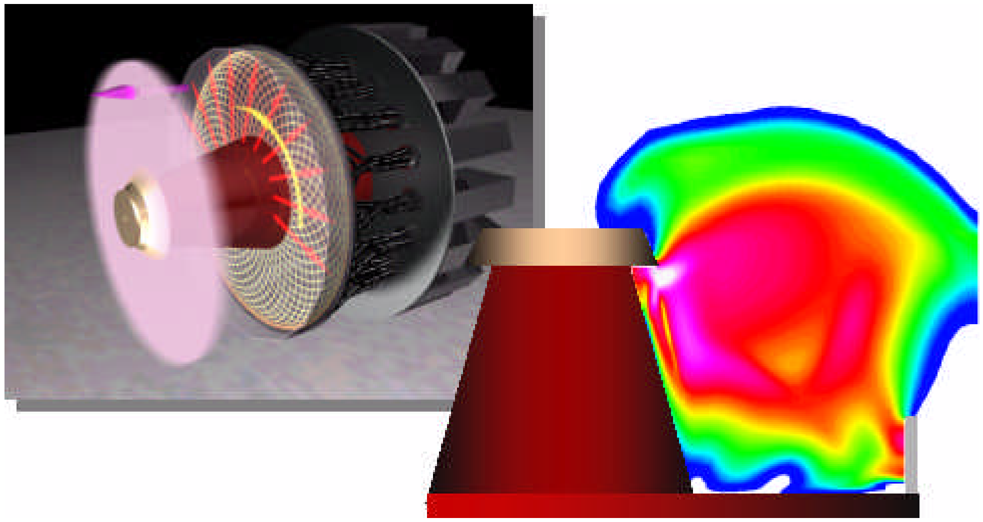
The On-Board Propulsion program at the NASA Glenn Research Center is utilizing a state-of-the-art numerical simulation to model the performance of high-power electromagnetic plasma thrusters. Such thrusters are envisioned for use in lunar and Mars cargo transport, piloted interplanetary expeditions, and deep-space robotic exploration of the solar system. The experimental portion of this program is described in reference 1. This article describes the numerical modeling program used to guide the experimental research. The synergistic use of numerical simulations and experimental research has spurred the rapid advancement of high-power thruster technologies for a variety of bold new NASA missions.

From its inception as a U.S. Department of Defense code in the mid-1980's, the Multiblock Arbitrary Coordinate Hydromagnetic (MACH) simulation tool has been used by the plasma physics community to model a diverse range of plasma problems--including plasma opening switches, inertial confinement fusion concepts, compact toroid formation and acceleration, z-pinch implosion physics, laser-target interactions, and a variety of plasma thrusters. The MACH2 code used at Glenn is a time-dependent, two-dimensional, axisymmetric, multimaterial code with a multiblock structure. MACH3, a more recent three-dimensional version of the code, is currently undergoing beta tests. The MACH computational mesh moves in an arbitrary Lagrangian-Eulerian (ALE) fashion that allows the simulation of diffusive-dominated and dispersive-dominated problems, and the mesh can be refined via a variety of adaptive schemes to capture regions of varying characteristic scale. The mass continuity and momentum equations model a compressible viscous fluid, and three energy equations are used to simulate nonthermal equilibrium between electrons, ions, and the radiation field. Magnetic fields are modeled by an induction equation that includes resistive diffusion, the Hall effect, and a thermal source for magnetic fields. Various models of plasma resistivity are included, along with ablation models and multiport circuit solvers. The set of equations is closed using either an ideal gas or real equation of state.



Superimposed current (line contours at 10-percent increments) and mass density (flooded contours) distributions from a MACH2 magnetoplasmadynamic thruster simulation. Hydrogen mass flow, 1.37 g/sec; thruster current, 6 kA.

The code was used recently at Glenn to simulate the performance of megawatt-class self-field magnetoplasmadynamic thrusters with material expansion nozzles (see the preceding figure). Such devices may offer improved efficiency over conventional self-field thrusters through the enhanced recovery of frozen flow losses. Additional modeling efforts are underway to simulate the performance of the TRW Pulsed Inductive Thruster (see the following figure), an electrodeless device that may circumvent the material erosion limits of conventional plasma thrusters to provide high efficiency over a range of specific impulse values.



Pulsed Inductive Thruster hardware, basic acceleration mechanism, and MACH2-simulated mass density distribution.

Reference

1. LaPointe, Michael R.; and Mikellides, Pavlos G.: High-Power Electromagnetic Thruster Being Developed. Research & Technology 2001, NASA/TM-2002-211333, 2002, pp. 51-53.

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